

# Chapter 1-Exploring Life

## Overview:

- **Biology** is the scientific study of life.
- You are starting your study of biology during its most exciting era.
- The largest and best-equipped community of scientists in history is beginning to solve problems that once seemed unsolvable.
  - °Biology is an ongoing **inquiry** about the nature of life.
- Biologists are moving closer to understanding:
  - °How a single cell develops into an adult animal or plant.
  - °How plants convert solar energy into the chemical energy of food.
  - °How the human mind works.
  - °How living things interact in biological communities.
  - °How the diversity of life evolved from the first microbes.
- Research breakthroughs in genetics and cell biology are transforming medicine and agriculture.
  - °Neuroscience and evolutionary biology are reshaping psychology and sociology.
  - °Molecular biology is providing new tools for anthropology and criminology.
  - °New models in ecology are helping society to evaluate environmental issues, such as the causes and biological consequences of global warming.
- Unifying themes pervade all of biology.

## A. Exploring Life on Its Many Levels

### Objectives:

1. Briefly describe the unifying themes that characterize the biological sciences.
  2. Diagram the hierarchy of structural levels in biological organization.
  3. Explain how the properties of life emerge from complex organization.
  4. Describe the two major dynamic processes of any ecosystem.
  5. Distinguish between prokaryotic and eukaryotic cells.
  6. Describe the basic structure and function of DNA.
  7. Describe the dilemma of reductionism.
  8. Discuss the goals and activities of systems biology. List three research developments that have advanced systems biology.
1. Explain the importance of regulatory mechanisms in living things. Distinguish between positive and negative feedback.

### Misconceptions:

1. Point out to your students that the universal genetic code provides the best evidence of a common ancestry for all life.
2. The concept of emergent properties is a difficult one for students to master. Provide examples of properties that emerge at each level in the hierarchy of biological organization in order to clarify this concept.

## Notes:

- Life's basic characteristic is a high degree of order.
- Biological organization is based on a **hierarchy** of structural levels, each building on the levels below.
  - At the lowest level are atoms that are ordered into complex biological molecules.
  - Biological molecules are organized into structures called **organelles**, the components of cells.
  - **Cells** are the fundamental unit of structure and function of living things.
- Some organisms consist of a single cell; others are multicellular **aggregates** of specialized cells.
  - Multicellular organisms exhibit three major structural levels above the cell: similar cells are grouped into tissues, several tissues coordinate to form organs, and several organs form an organ system.
- Whether multicellular or unicellular, all organisms must accomplish the same functions:
  - uptake and processing of nutrients,
  - excretion of wastes,
  - response to environmental **stimuli**,
  - reproduction.

### ***1. Organisms interact continuously with their environment.***

- Each organism interacts with its **environment**, which includes other organisms as well as nonliving factors.
  - Organisms belong to **populations**, localized groups of organisms belonging to the same species.
  - Populations of several species in the same area comprise a biological **community**.
  - Populations interact with their physical environment to form an **ecosystem**.
  - The **biosphere** consists of all the environments on Earth that are inhabited by life.
- Both organism and environment are affected by the interactions between them.
- The dynamics of any ecosystem include two major processes: the cycling of nutrients and the flow of energy from sunlight to producers to consumers.
  - In most ecosystems, producers are plants and other **photosynthetic** organisms that convert light energy to chemical energy.
  - Consumers are organisms that feed on producers and other consumers.
- All the activities of life require organisms to perform work, and work requires a source of energy.
  - The exchange of energy between an organism and its environment often involves the transformation of energy from one form to another.
  - In all energy transformations, some energy is lost to the surroundings as heat.
  - In contrast to chemical nutrients, which recycle within an ecosystem, energy flows through an ecosystem, usually entering as light and exiting as heat.

### ***2. Cells are an organism's basic unit of structure and function.***

- The cell is the lowest level of structure that is capable of performing all the activities of life.
- Understanding how cells work is a major research focus of modern biology.
- At some point, all cells contain deoxyribonucleic acid, or **DNA**, the heritable material that directs the cell's activities.
  - DNA is responsible for maintaining cellular functioning (via its **genes**, which allow a cell to build protein).
  - Almost all cellular activities involve the action of one or more proteins.
  - DNA is **heritable**. It maintains continuity between different generations of organisms.

°Each of us began life as a single cell stocked with DNA inherited from our parents.

°In humans, DNA is organized into **chromosomes**; very long DNA molecules with hundreds or thousands of genes arranged along their length.

°The DNA of chromosomes replicates as a cell prepares to divide.

°Each of the two cellular offspring inherits a complete set of genes.

°DNA provides the heritable blueprints, but proteins are the tools that actually build and maintain the cell.

°The chromosomes of each human cell contain about 3 billion nucleotides, including genes coding for more than 70,000 kinds of proteins, each with a specific function.

- All forms of life employ essentially the same genetic code, a fact taken advantage of by **genetic engineering**.
- Every cell is enclosed by a **membrane** that regulates the passage of material between a cell and its surroundings.
- There are two basic types of cells: **prokaryotic** cells and **eukaryotic** cells.
- The cells of the microorganisms called bacteria and archaea are prokaryotic.
- All other forms of life have more complex eukaryotic cells.
  - °In most eukaryotic cells, the largest organelle is the nucleus, which contains the cell's DNA as chromosomes.
- Prokaryotic cells are much simpler and smaller than eukaryotic cells.
  - °In a prokaryotic cell, DNA is not separated from the cytoplasm in a nucleus.
- All cells, regardless of size, shape, or structural complexity, are highly ordered structures that carry out complicated processes necessary for life.

### ***3. Biological systems are much more than the sum of their parts.***

- **The Law of Combinatoriality:** As more components are added to a system, the interaction between those components increases exponentially.
  - °Examples of biological systems are cells, organisms, and ecosystems.
- Consider the levels of life: With each step upward in the hierarchy of biological order, novel properties emerge that are not present at lower levels.
- These **emergent properties** result from the arrangements and interactions between components as complexity increases.
  - °A cell is much more than a bag of molecules.
  - °Our thoughts and memories are emergent properties of a complex network of neurons.
- The emergent properties of life are not supernatural or unique to life but simply reflect a hierarchy of structural organization.
- The complex organization of life presents a dilemma to scientists seeking to understand biological processes.
  - °We cannot fully explain a higher level of organization by breaking it down into its component parts.
  - °At the same time, it is futile to try to analyze something as complex as an organism or cell without taking it apart.
- **Reductionism**, reducing complex systems to simpler components, is a powerful strategy in biology.
- The ultimate goal of **systems biology** is to **model** the dynamic behavior of whole biological systems.
  - °Accurate models allow biologists to predict how a change in one or more variables will impact other components and the whole system.

- Scientists investigating ecosystems pioneered this approach in the 1960s with elaborate models diagramming the interactions of species and nonliving components in ecosystems.
- Systems biology is now becoming increasingly important in cellular and molecular biology.  
°In 2003, a large research team published a network of protein interactions within a cell of a fruit fly.

#### ***4. Regulatory mechanisms ensure a dynamic balance in living systems.***

- Chemical processes within cells are accelerated, or catalyzed, by specialized protein molecules, called **enzymes**.
- Each type of enzyme catalyzes a specific chemical reaction.  
°In many cases, reactions are linked into chemical pathways, each step with its own enzyme.
- How does a cell coordinate its various chemical pathways?  
°Many biological processes are **self-regulating**.  
°In **negative feedback**, or **feedback inhibition**, accumulation of an end product of a process slows or stops that process.
- Though less common, some biological processes are regulated by **positive feedback**, in which an end product speeds up its own production.  
°Feedback is common to life at all levels, from the molecular level to the biosphere.
- Such regulation is an example of the integration that makes living systems much greater than the sum of their parts.

### **B. Evolution, Unity, and Diversity**

#### **Objectives:**

1. Distinguish among the three domains of life. List and distinguish among the three kingdoms of multicellular, eukaryotic life.
2. Explain the phrase “life’s dual nature of unity and diversity.”
3. Describe the observations and inferences that led Charles Darwin to his theory of evolution by natural selection.
4. Explain why diagrams of evolutionary relationships have a treelike form.

#### **Misconceptions:**

1. Many students do not recognize the extent to which life has shaped the Earth. Although students may acknowledge that living things interact with the abiotic components of their environment, they may not realize the extent to which the atmosphere, oceans, and land of our modern Earth have been changed by life.

#### **Notes:**

##### ***1. The unity and diversity of life.***

- Life is enormously **diverse**.  
°Biologists have identified and named about 1.8 million species.
- This diversity includes 5,200 known species of prokaryotes, 100,000 fungi, 290,000 plants, 50,000 vertebrates, and 1,000,000 insects.
- Thousands of newly identified species are added each year.  
°Estimates of the total species count range from 10 million to more than 200 million.
- In the face of this complexity, humans are inclined to categorize diverse items into a smaller number of groups.  
°**Taxonomy** is the branch of biology that names and classifies species into a hierarchical order.

- Until the past decade, biologists divided the diversity of life into five **kingdoms**.
- New methods, including comparisons of DNA among organisms, have led to a reassessment of the number and boundaries of the kingdoms.
- Various classification schemes now include six, eight, or even dozens of kingdoms.
- Coming from this debate has been the recognition that there are three even higher levels of classifications, the domains.
  - The three **domains** are **Bacteria**, **Archaea**, and **Eukarya**.
  - The first two domains, domain Bacteria and domain Archaea, consist of prokaryotes.
- All the eukaryotes are now grouped into various kingdoms of the domain Eukarya.
  - The recent taxonomic trend has been to split the single-celled eukaryotes (“**Kingdom Protista**”) and their close relatives into several kingdoms.
- Domain Eukarya also includes the three kingdoms of multicellular eukaryotes: the kingdoms **Plantae**, **Fungi**, and **Animalia**. These kingdoms are distinguished partly by their modes of nutrition.
- Underlying the diversity of life is a striking unity, especially at the lower levels of organization.
  - The universal genetic language of DNA unites prokaryotes and eukaryotes.
  - Among eukaryotes, unity is evident in many details of cell structure.
  - Above the cellular level, organisms are variously adapted to their ways of life.
- The process of **evolution** explains both the similarities and differences among living things.

## ***2. Evolution is the core theme of biology.***

- The history of life is a saga of a changing Earth billions of years old, inhabited by a changing cast of living forms.
- Charles Darwin brought evolution into focus in 1859 when he presented two main concepts in one of the most important and controversial books ever written, On the Origin of Species by Means of Natural Selection.
- Darwin’s first point was that contemporary species arose from a succession of ancestors through “descent with modification.”
- Darwin’s second point was his mechanism for descent with modification: **natural selection**.
- Darwin inferred natural selection by connecting two observations:
  - Observation 1: Individual variation. Individuals in a population of any species vary in many heritable traits.
  - Observation 2: Overpopulation and competition. Any population can potentially produce far more offspring than the environment can support. This creates a struggle for existence among variant members of a population.
  - Inference: Unequal reproductive success. Darwin inferred that those individuals with traits best suited to the local environment would leave more healthy, fertile offspring.
  - Inference: Evolutionary adaptation. Unequal reproductive success can lead to adaptation of a population to its environment. Over generations, heritable traits that enhance survival and reproductive success will tend to increase in frequency among a population’s individuals. The population evolves.
- Natural selection, by its cumulative effects over vast spans of time, can produce new species from ancestral species.
- Biologists’ diagrams of evolutionary relationships generally take a treelike form.
- Just as individuals have a family tree, each species is one twig of a branching tree of life.
- All of life is connected through its long evolutionary history.

## **C. The Process of Science**

### Objectives:

1. Distinguish between discovery science and hypothesis-based science. Explain why both types of exploration contribute to our understanding of nature.
2. Distinguish between quantitative and qualitative data.
3. Distinguish between inductive and deductive reasoning.
4. Explain why hypotheses must be testable and falsifiable but are not provable.
5. Describe what is meant by a controlled experiment.
6. Distinguish between the everyday meaning of the term *theory* and its meaning to scientists.
7. Explain how science is influenced by social and cultural factors.
8. Distinguish between science and technology. Explain how science and technology are interdependent.

### Misconceptions:

1. Students tend to think that there is one universally applied scientific method, and that all “real science” is hypothesis-driven and experimental. As a result of this misunderstanding, students may discount theories about historical events. Impress upon your students that scientists use many different methods to investigate biological questions.
2. Students may have difficulty understanding that scientific hypotheses cannot be proven. An example that may help to illustrate this is the recent modification of the long-accepted five-kingdom theory of biological diversity, which has been replaced with a theory of three domains and additional kingdoms based on new evidence from DNA comparisons of living organisms.

### Notes:

#### ***1. Biologists use various forms of inquiry to explore life.***

- The word **science** is derived from a Latin verb meaning “to know.”
- Scientific pursuits are as old as humanity itself.
- There is an idealized process of inquiry called **the scientific method**.
  - °Very few scientific inquiries adhere rigidly to the sequence of steps prescribed by the textbook scientific method.
- At the heart of science is inquiry, people asking questions about nature and focusing on specific questions that can be answered.
- The process of science blends two types of exploration: discovery science and hypothesis-based science.
  - °**Discovery science** is mostly about discovering nature.
  - °**Hypothesis-based science** is mostly about explaining nature.
  - °Most scientific inquiry combines the two approaches.
- Discovery science describes natural structures and processes as accurately as possible through careful observation and analysis of data.
- **Observation** is the use of the senses to gather information, which is recorded as data.
- Data can be **qualitative** or **quantitative**.
  - °Quantitative data are numerical measurements.
  - °Qualitative data may be in the form of recorded descriptions.
- Discovery science can lead to important conclusions based on inductive reasoning.
  - °Through induction, we derive generalizations based on a large number of specific observations.
- In science, inquiry frequently involves the proposing and testing of **hypotheses**.

°A hypothesis is a tentative answer to a well-framed question.

- A scientific hypothesis makes predictions that can be tested by recording additional observations or by designing experiments.
- A type of logic called **deduction** is built into hypothesis-based science.
  - °In deductive reasoning, reasoning flows from the general to the specific.
  - °From general premises, we extrapolate to a specific result that we should expect if the premises are true.
- In hypothesis-based science, deduction usually takes the form of predictions about what we should expect if a particular hypothesis is correct.
- Scientific hypotheses must be **testable**.
  - °There must be some way to check the validity of the idea.
- Scientific hypotheses must be **falsifiable**.
  - °There must be some observation or experiment that could reveal if a hypothesis is actually not true.
- The ideal in hypothesis-based science is to frame two or more alternative hypotheses and design experiments to falsify them.
  - °Typically, these experiments examine the effects of a single variable.
  - °Scientists endeavor to **control** all other variables in the experiment, NOT by eliminating them, but by eliminating their effects on the experiment.
- **No amount of experimental testing can prove a hypothesis.**
- A hypothesis gains support by surviving various tests that could falsify it, while testing falsifies alternative hypotheses.
- **Facts**, in the form of verifiable observations and repeatable experimental results, are the prerequisites of science.

## **2. The nature of science.**

- There are limitations to the kinds of questions that science can address.
- These limits are set by science's requirements that hypotheses are testable and falsifiable and that observations and experimental results be repeatable.
- The limitations of science are set by its **naturalism**.
  - °Science seeks natural causes for natural phenomena.
  - °Science cannot support or falsify supernatural explanations, which are outside the bounds of science.
- Everyday use of the term theory implies an untested speculation.
- The term **theory** has a very different meaning in science.
- A scientific theory is much broader in scope than a hypothesis.
  - °This is a hypothesis: "Mimicking poisonous snakes is an adaptation that protects nonpoisonous snakes from predators."
  - °This is a theory: "Evolutionary adaptations evolve by natural selection."
- A theory is general enough to generate many new, specific hypotheses that can be tested.
- Compared to any one hypothesis, a theory is generally supported by a much more massive body of evidence.
- The theories that become widely adopted in science (such as the theory of adaptation by natural selection) explain many observations and are supported by a great deal of evidence.
- In spite of the body of evidence supporting a widely accepted theory, scientists may have to modify or reject theories when new evidence is found.

°As an example, the five-kingdom theory of biological diversity eroded as new molecular methods made it possible to test some of the hypotheses about the relationships between living organisms.

- Scientists may construct **models** in the form of diagrams, graphs, computer programs, or mathematical equations.
  - °Models may range from lifelike representations to symbolic schematics.
- Science is an intensely social activity.
- Both cooperation and competition characterize scientific culture.
  - °Scientists attempt to confirm each other's observations and may repeat experiments.
  - °They share information through publications, seminars, meetings, and personal communication.
  - °Scientists may be very competitive when converging on the same research question.
- Science as a whole is embedded in the culture of its times.
  - °For example, recent increases in the proportion of women in biology have had an impact on the research being performed.
- For instance, there has been a switch in focus in studies of the mating behavior of animals from competition among males for access to females to the role that females play in choosing mates.
- Some philosophers of science argue that scientists are so influenced by cultural and political values that science is no more objective than other ways of "knowing nature."
  - °At the other extreme are those who view scientific theories as though they were natural laws.
- The reality of science is somewhere in between.
- The cultural **milieu** affects scientific fashion, but need for repeatability in observation and hypothesis testing distinguishes science from other fields.
- If there is "truth" in science, it is based on a preponderance of the available evidence.

### ***3. Science and technology are functions of society.***

- Although science and technology may employ similar inquiry patterns, their basic goals differ.
  - °The goal of science is to understand natural phenomena.
  - °**Technology** applies scientific knowledge for some specific purpose.
- Technology results from scientific discoveries applied to the development of goods and services.
- Scientists put new technology to work in their research.
- **Science and technology are interdependent.**
- The direction that technology takes depends less on science than it does on the needs of humans and the values of society.
  - °Debates about technology center more on "should we do it" than "can we do it."
- With advances in technology come difficult choices, informed as much by politics, economics, and cultural values as by science.
- Scientists should educate politicians, bureaucrats, corporate leaders, and voters about how science works and about the potential benefits and hazards of specific technologies.

## **Key Terms**

archaea  
bacteria  
bioinformatics  
biology  
biosphere  
cell

community  
consumer  
controlled experiment  
data  
deductive reasoning  
deoxyribonucleic acid (DNA)

discovery science  
domain Archaea  
domain Bacteria  
domain Eukarya  
ecosystem  
emergent properties



eukaryotic cell  
gene  
genome  
hypothesis  
inductive reasoning  
inquiry  
kingdom Animalia  
kingdom Fungi  
kingdom Plantae

model  
molecule  
negative feedback  
organ  
organ system  
organelle  
organism  
population  
positive feedback

producer  
prokaryotic cell  
reductionism  
system  
systems biology  
technology  
theory  
tissue

## Word Roots

**bio-** 5 life (*biology*: the scientific study of life; *biosphere*: all the environments on Earth that are inhabited by life; *bioinformatics*: using information technology to extract useful information from large sets of biological data)

**eu-** 5 true (*eukaryotic cell*: a cell that has a true nucleus)

**-ell** 5 small (*organelle*: a small, formed body with a specialized function found in the cytoplasm of eukaryotic cells)

**pro-** 5 before; **karyo-** 5 nucleus (*prokaryotic cell*: a cell that has no nucleus)